

STATE OF ARIZONA
DEPARTMENT OF WATER RESOURCES
ENGINEERING DIVISION

State Standard

for

Identification of and Development Within

Sheet Flow Areas

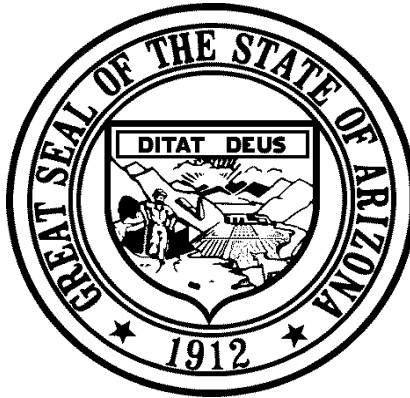
Under authority of ARS 45-3605(a), the Director of the Arizona Department of Water Resources establishes the following standard for identification of and development within sheet flow areas in Arizona:

Identification of, or regulation of development within, sheet flow areas in Arizona for use in fulfilling the requirements of Flood Insurance Studies, and local community and county flood damage prevention ordinances will use the guidelines outlined in State Standard Attachment 4-95 entitled "Identification of and Development Within Sheet Flow Areas" or an alternative procedure reviewed and accepted by the Director.

For the purpose of application of these guidelines, sheet flow areas will include all sheet flow areas identified by the Federal Emergency Management Agency as part of the National Flood Insurance Program, all sheet flow areas which have been identified by a local floodplain administrator as having significant potential flood hazards, sheet flow floodplains meeting the site identification criteria outlined in Attachment 4-95 with drainage areas more than 1/4 square mile or a 100-year estimated flow of more than 500 cubic feet per second. Application of these guidelines will not be necessary if the local community or county has in effect a drainage, grading, or stormwater ordinance which, in the opinion of the Department, results in the same or greater level of flood protection as application of these guidelines would ensure.

This requirement is effective January 1, 1995. Copies of this State Standard and State Standard Attachment 4-95 can be obtained by contacting the Department's Engineering Division at (602) 417-2445.

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Identification of and Development
within
Sheet Flow Areas

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Disclaimer of Liability

The methods contained in this publication are intended to be a reasonable way of setting minimum floodplain management requirements where better data or methods do not exist. As in all technical methods, engineering judgement and good common sense must be applied and the methods rejected where they obviously do not offer a reasonable solution.

It must be recognized that while the criteria established herein will generally reduce flood damages to new and existing development, there will continue to be flood damages in Arizona.

Where future-condition hydrology (which considers the cumulative effects of development) is not used, future development will probably increase downstream runoff, which may result in flooding. Unlikely or unpredictable events such as earthquakes or dam failures may also cause extreme flooding.

The Arizona Department of Water Resources is not responsible for the application of the methods outlined in this publication and accepts no liability for their use. Sound engineering judgement is recommended in all cases.

The Arizona Department of Water Resources reserves the right to modify, update or otherwise revise this document and its methodologies. Questions regarding information or methodologies contained in this document and/or floodplain management should be directed to the local floodplain administrator or the office below:

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Introduction

Sheet flooding is a type of surface water runoff that occurs on broad, unconfined floodplains with low relief. Sheet flooding can occur in urban, rural, and natural areas. Because sheet flooding often occurs in areas that lack defined stream channels, identification of sheet flood areas can be difficult. Although types of sheet flooding have been identified in every geographic region of Arizona, floodplain management standards for sheet flood areas are generally lacking. This state standard for development in sheet flow areas is intended to promote sound floodplain management of these unique hazard areas.

This document details minimum floodplain management standards for identification of and development within sheet flooding areas in Arizona. Types of sheet flooding are defined, and identifying characteristics are given for each type. Flood hazards associated with sheet flooding are described. General floodplain management requirements and recommended development guidelines are presented. Three methods of sheet flow hydraulic analysis are presented which reflect increased levels of complexity and accuracy. Finally, sample applications of the standards are provided to demonstrate application of the development standards.

Definitions and Identifying Characteristics

Sheet flow is a loosely defined term, as it is used in Arizona. In general, the term "sheet flow" may refer to any form of unconfined runoff that occurs over a broad, expansive area. This broad definition of sheet flow incorporates several more narrowly defined flow types, including natural (classic) sheet flow, urban sheet flow, agricultural sheet flow, overland flow, perched flow, anastomosing flow, and distributary flow. The variety of terms used for sheet flow probably reflects the variety of flow types that occur within specific geographic regions of the state. For this study, definitions of types of sheet flooding are provided for use by regulatory agencies. The term "sheet flow" will be used generically, to include all types defined within this document.

In general, sheet flooding in Arizona may have the following characteristics:

- The primary identifying characteristic of sheet flow is that a significant part of floodwater is not conveyed in a single, well-defined channel. Flood flow is conveyed over the unchannelized land surface.
- Water moving over a smooth stable surface does not move as a uniform film. If the surface is broad, the sheet differentiates into parallel streams of greater depth and relatively rapid flow, separated by shallower bands of relatively sluggish flow; and at the same time, both streams and intervening bands differentiate into series of transverse waves which move forward more rapidly than the body of the undifferentiated sheet.
- Sheet flow over poorly vegetated surfaces often has the ability to transport large sediment particles relatively large distances over low slopes without significant reduction in sediment diameter, angularity, or degree of sorting, such as may be considered typical of most well defined streams.

- Sheet flooding has markedly different hydraulic characteristics for sediment laden and sediment deprived flows. Sheet flooding may not have gradually varied or steady flow, and may have a strong two-dimensional character.
- Significant loss of flow volume may occur during sheet flooding due to infiltration and other abstractions.
- Sheet flow often enters a larger channel or drainage system that intersects its flow, but occasionally dissipates due to infiltration or other loss mechanisms before ever reaching a channel.

In addition to these general characteristics of sheet flow, the specific types of sheet flow found in Arizona have unique identifying characteristics, described below.

Natural Sheet Flow

Natural sheet flow is flowing water characterized by a tendency to spread widely in relatively shallow sheets over gently sloping areas with low topographic relief which lack defined drainage systems. Figure 1 shows a natural sheet flow area.

Identifying characteristics of natural sheet flow areas include:

- Low topographic relief perpendicular to the primary flow direction.
- Very poorly defined channels (or none) downstream of a relatively large drainage area. When viewed on aerial photographs, no channel banks may be readily identified.
- Very uniform vegetative characteristics that extend laterally over an expansive area affected by sheet flow. Many natural sheet flow areas are covered by grass.
- Soil characteristics may not be visible on aerial photographs due to vegetation density. Soils characteristics are usually very uniform within the sheet flow area. In lower desert regions, very little surficial soil reddening may be present.
- Soil units mapped by the Soil Conservation Service as floodplain soils.



0 1000 feet

A horizontal black scale bar representing 1000 feet.

Figure 1
Natural Sheet Flow Area

Urban Sheet Flow

Urban sheet flow occurs where development has obscured natural drainage patterns or where urban drainage facilities are severely undersized. Urban sheet flow areas differ from natural sheet flow areas in that identifying soil and vegetative characteristics may be obscured by development. Urban sheet flow areas are usually identified from historic records of unconfined flooding. Urban sheet flow areas occasionally may be identified by detailed topographic maps that show low relief in known flooding areas. Figure 2 shows an urban sheet flow area.

Identifying characteristics of urban sheet flow areas include:

- Low topographic relief perpendicular to the primary flow direction.
- Lack of defined channels downstream of a relatively large drainage area.
- Significant flow in streets during ordinary rainstorms.

Distributary Flow

Distributary flow areas¹ have channels which split and rejoin in a complex pattern. The number of channel forks commonly exceeds the number of channel confluences, creating a *distributary*, rather than tributary drainage pattern. The separate channels downstream of a channel fork may have terraces independent of other channels within the distributary flow system. A distributary channel is a stream branch flowing away from the main stream and not rejoining it. Distributary flow may be characterized as sheet flow with a strong channelized flow component. Figure 3 shows a distributary flow area.

Identifying characteristics of distributary flow areas include:

- Low, but distinguishable topographic relief perpendicular to the primary flow direction. Topographic relief is sufficient to create isolated islands during flood conditions within the overall floodplain.
- Channels which divide in the downstream direction so that the number of flow paths conveying floodwaters increases in the downstream direction. Distributary flow may occur on alluvial fans.
- An increase in vegetative density along flow lines, with more uniform upland vegetation types found between flow lines, extending laterally over an expansive area.
- Soils units mapped by the Soil Conservation Service as alluvial fan terraces, inactive alluvial fans, or alluvial fans.

¹ See Hjalmanson and Kemna, 1991 for additional information.



0 1200 feet


 A horizontal scale bar representing 1200 feet, with the number "0" at the left end and "1200 feet" at the right end.

Figure 2

**Urban Sheet Flow Area With
Moderate Development Density**

Note Flow patterns in adjacent
natural areas



0 1000 feet

A solid black horizontal line representing a scale of 1000 feet.

Figure 3
Distributary Flow Area

- During large floods, the distribution of flow between various existing distributary flow paths may not be predictable. However, flow lines are relatively stable, especially during smaller floods.
- Large floods may cause isolated or widespread bank erosion, or sediment deposition within the channel which changes channel capacity or may change overbank conveyance.

Anastomosing Flow

Anastomosing² flow is quasi-sheet flooding with slightly incised flow lines which creates a system of interwoven channels. This type of anastomosing is found in intermittent to perennial stream systems with net long-term erosion, in contrast to braided streams which are characterized by net long-term deposition, and which occur within well-defined floodplains. Anastomosing flow differs from sheet flow (greater) and distributary flow by the (lesser) degree of flow line incision. Anastomosing streams are geologically temporary features. Figure 4 shows an anastomosing flow area.

Identifying characteristics of anastomosing flow areas include:

- An anastomosing stream has branching, interlacing, and interconnecting flow paths, which produce a net-like or braided appearance.
- Anastomosing flow areas have slight topographic relief perpendicular to the primary flow direction.
- Anastomosing flow areas have poorly defined channels downstream of a relatively large drainage area. When viewed on aerial photographs, channel banks may not be visible for large portions of the anastomosing alluvial surface. Anastomosing may occur on the lowest portion of alluvial fans.
- An increase in vegetative density may occur along flow lines in anastomosing flow areas, with uniform vegetative characteristics between flow lines, extending laterally over an expansive area.
- Soils mapped by the Soil Conservation Service as floodplain soils.

² The term anastomosing means netted; intervened; and is also used to describe leaves marked by cross veins forming a network; sometimes the vein branches meet only at the margin.



Note:
Exact photo scale and aspect unknown

Figure 4
Anastomosing Flow Area During
October 1954 Flood

Agricultural Sheet Flow

Agricultural sheet flow occurs on land surfaces that have been graded or flattened for agricultural use. Lack of topographic variation within the field create sheet flow conditions.

Agricultural sheet flow areas differ from natural sheet flow areas in that soil and vegetative identifying characteristics may be obscured by regrading or leveling for irrigation and crop development. Agricultural sheet flow areas may be identified from pre-development photographic or topographic data, or from historic records of flooding. Figure 5 shows a agricultural sheet flow area.

Identifying characteristics of agricultural sheet flow areas include:

- Distributary, anastomosing, or sheet flow channel patterns which are intercepted in the downstream direction by agricultural areas which have no identified drainage facilities.
- Low topographic relief perpendicular to the primary flow direction.

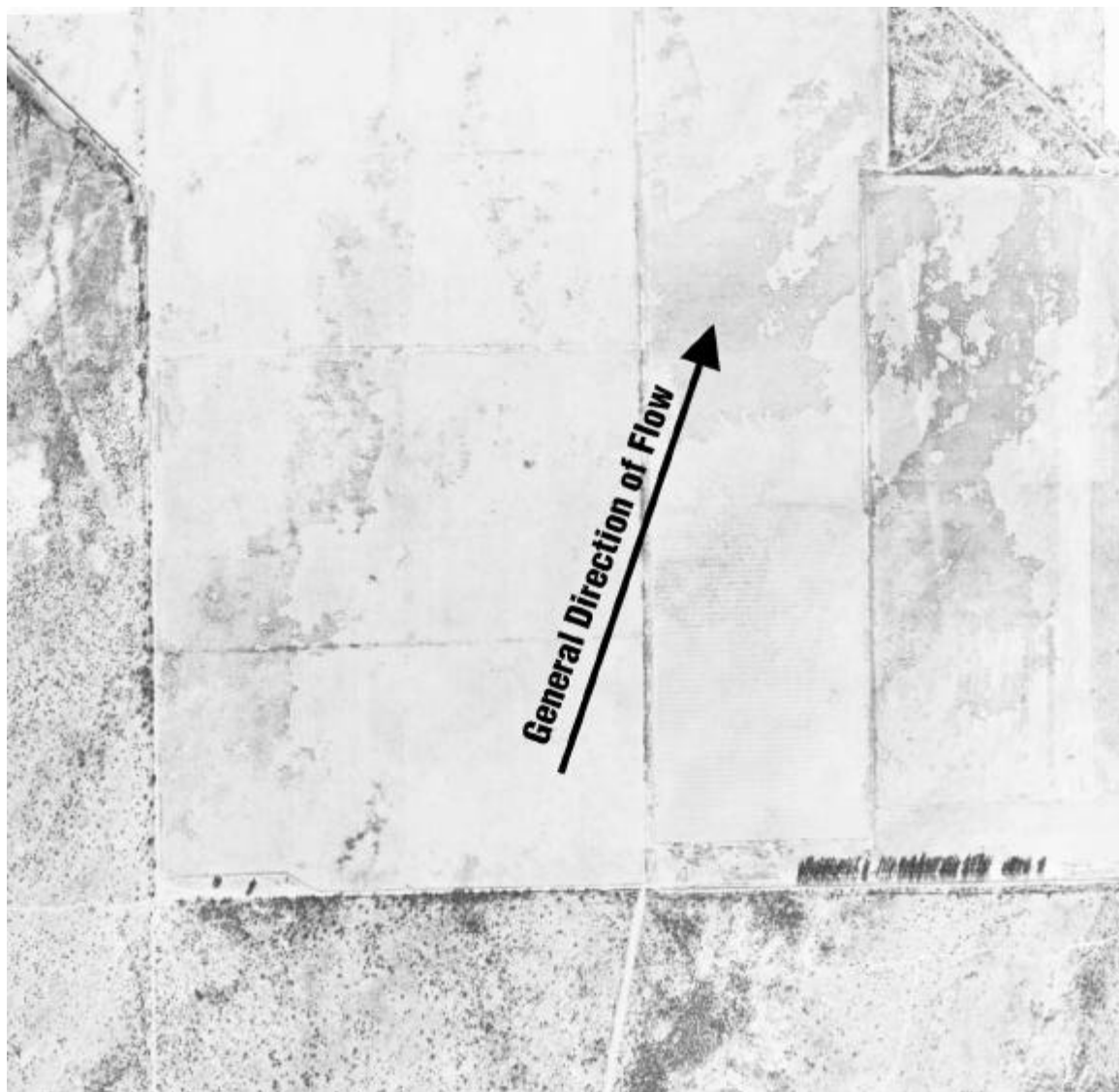
Overland Flow

Overland flow is the movement of water resulting from rainfall on hill slopes in upper watershed areas prior to entering defined channels. The development standards detailed in this document should not be applied to overland flow areas. Overland flow is illustrated in Figure 6.

Identifying characteristics of overland flow areas include:

- Overland flow occurs over relatively short distances between the point where surface runoff begins and a nearby, well-defined channel.
- Overland flow occurs near the watershed divides, rather than at the outlet of a watershed, at depths usually less than 6 inches.
- Overland flow usually is a site drainage concern, rather than a regional floodplain management problem.
- Overland flow areas may have a micro-drainage pattern which may be distributary, anastomosing, or completely lacking, but which generally flow into a tributary drainage network.

Overland flow is generally not an important consideration for floodplain management. The development standards outlined in this document generally should not be applied to overland flow areas.



0 1000 feet



Figure 5

Agricultural Sheet Flow Area

Note Natural Sheet Flow Areas
Upstream of Fields

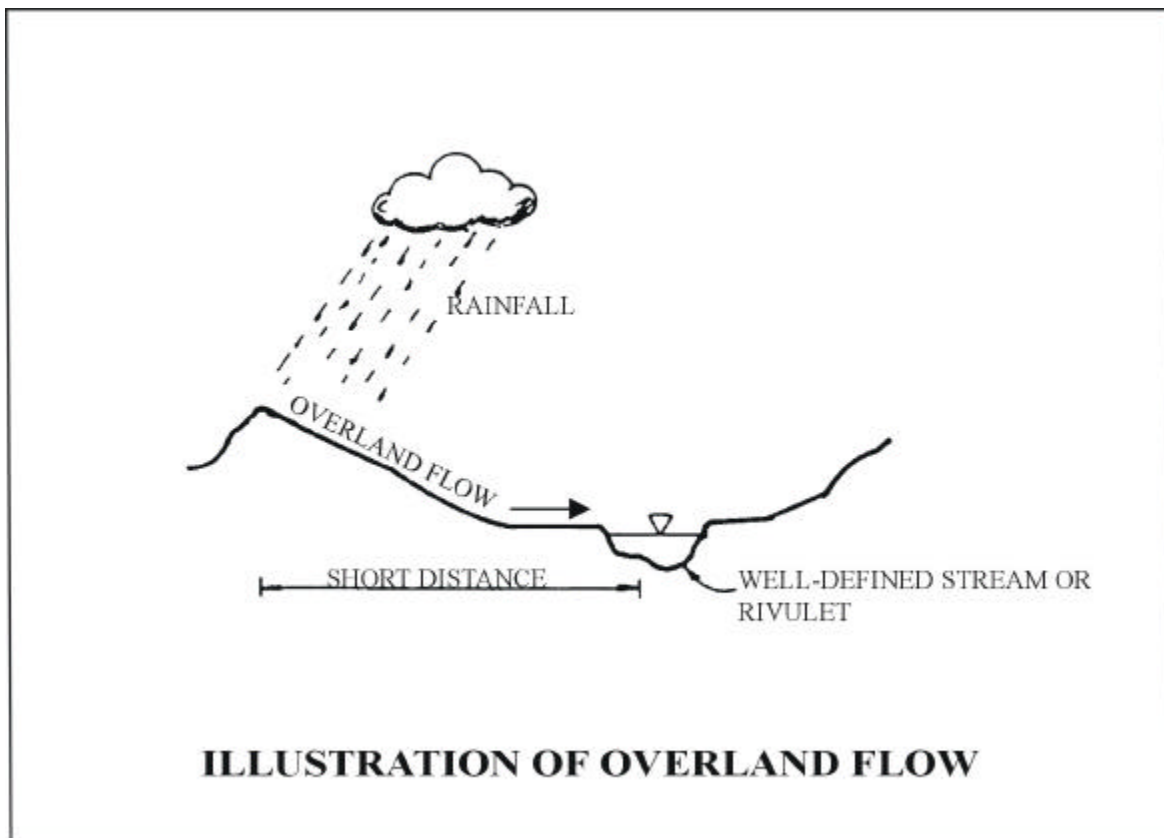


Figure 6

Perched Flow

Perched flow originates along well-defined channels where overbank flooding becomes separated from the main flow path, and develops hydraulic characteristics unique from the main channel. For this study, and for the proposed state standard, perched flow is not considered to be sheet flow, unless it meets other characteristics described above. Perched flow is illustrated in Figure 7.

Braided Flow

Braided flow occurs where flow within a well-defined channel or floodplain is divided into separate flow paths created by shifting patterns of sediment deposition. Braided flow is not a form of sheet flow. Braided flow is illustrated in Figure 8.

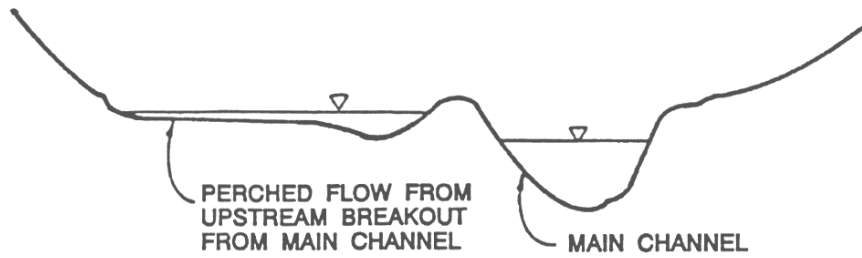


FIGURE 7
ILLUSTRATION OF PERCHED FLOW
CROSS - SECTION

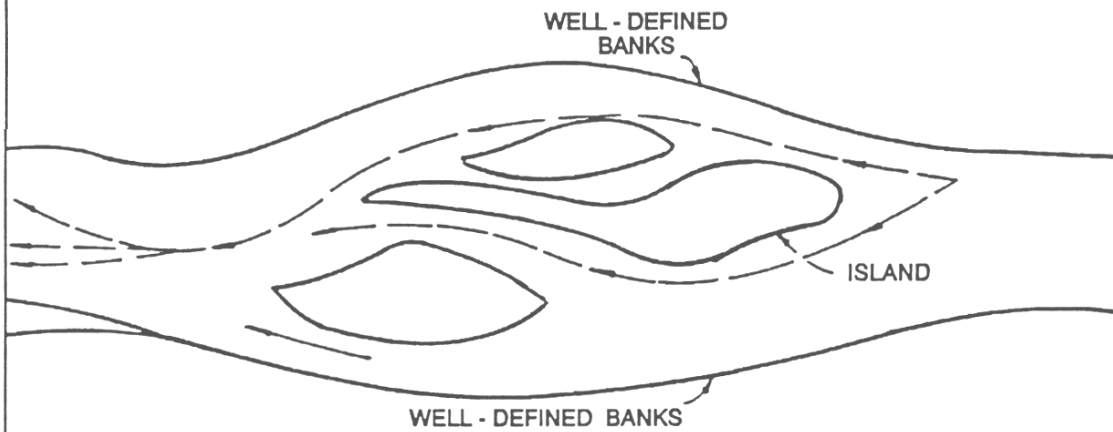


FIGURE 8
ILLUSTRATION OF BRAIDED FLOW
PLAN VIEW

Figure 7 and Figure 8

Sheet Flow Flood Hazards

Sheet flow areas are hydraulically and geomorphically different than riverine, alluvial fan, or other Arizona floodplains. They also have unique flood hazards, including:

- Sheet flooding often occurs in areas that have no defined channel or in areas between minor channels in anastomosing or distributary flow networks. Therefore, flood inundation may be unexpected by residents or landowners unfamiliar with sheet flow. Untrained observers may find no indication of the potential for flooding prior to developing a property.
- In sheet flow areas with minor channels, floods frequently exceed bank heights. Development above channel banks does not guarantee adequate flood protection.
- Distribution of runoff between channels may vary between storm events due to minor channel changes upstream. Hydrologic and hydraulic analyses should be done using conservative assumptions for drainage area to ensure that all areas that could contribute runoff are included. Minor watershed changes may significantly increase flood hazards at any given property.
- Sheet flooding may occur over such a broad expanse that a single given property may not have a significant portion which is less flood prone than any other portion.
- Some types of development in sheet flood areas may concentrate flow and alter flow conditions on downstream properties. Accessory development features such as fences, perimeter walls, or roads can have significant impacts on downstream flood hazards.
- Concentration of flow may result in channel (arroyo) formation and initiate headcuts that could propagate upstream and damage structures.
- If natural ground cover is disturbed, flow induced shear stresses on steep land surfaces may cause erosion.
- Sheet flooding over roadways with no drainage structures may prevent access of emergency vehicles for significant periods of time. Sediment deposition on road crossings in sheet flow areas may also delay property access.
- Significant backwater conditions may occur in sheet flow areas upstream of roadways with drainage structures that are not sized for the 100-year flood. Flood depths resulting from these backwater conditions may exceed depths indicated by local geomorphology or field conditions. Required finish floor elevations should consider the potential for backwater.
- Alteration of flow characteristics in sheet flow areas may also alter important wildlife habitat, groundwater recharge, or receiving water characteristics.

Development Standards for Sheet Flow Areas

Minimum development standards for management of all natural and urban sheet flow areas, distributary and anastomosing flow areas in Arizona are shown below. In addition, general recommendations for regulation of development in all sheet flow areas are also outlined. The minimum and recommended standards reflect the types of flood hazards identified for Arizona sheet flow areas.

Required Development Standards

Based on the criteria and information outlined above, the following are minimum standards for development in sheet flow areas:

Natural and Urban Sheet Flow Areas

Habitable structures built in areas subject to natural sheet flooding shall at minimum:

- Elevate the lowest finished floors of all habitable structures. Elevation requirements are described in the *Method of Flow Analysis* section of this document.
- Use appropriate site grading practices to direct nuisance runoff away from the building pad.

Distributary and Anastomosing Flow Areas

Habitable structures built in areas subject to distributary and anastomosing flooding shall at minimum:

- Elevate the lowest finished floor of all habitable structures. Elevation requirements are described in the *Method of Flow Analysis* section of this document.
- Protect the building foundation and related facilities from scour damage and from undercutting from erodible channel banks.
- Use appropriate site grading to direct nuisance runoff away from the building pad.

Recommended Development Standards

The following minimum standards are recommended, but not required, for development in all types of sheet flow areas:

Single Lot Development

- Chain link fences should be elevated 0.5 foot above adjacent grade (a single-strand wire may be allowed below the chain link), or be designed to collapse under hydrostatic pressure, or set back from property line.
- Fences over existing natural channels/flow paths should be elevated or configured to pass bankfull flows unobstructed. Fences that obstruct flow can trap flood debris, and cause erosion or diversion of flow.
- Solid perimeter walls should be set back from property lines to provide flow conveyance between lots, or should have the ability to pass drainage through the walls. Walls designed to pass drainage through should be designed to account for blockage of openings by vegetation and floating debris, and should be able to withstand hydrostatic pressure and scour caused by flow impingement.
- Site grading and building pad locations should allow for continuity of drainage for all recognizable flow paths.
- Homes in single lot developments should be aligned parallel to the primary flow direction.
- Manufactured housing should be anchored to prevent flotation and overturning.
- Building pads should be protected against scour damage.
- Zoning densities higher than 1 residence per acre (RAC) are not recommended in designated sheet flow areas unless drainage studies that analyze potential concentration of flow and downstream impacts are completed or regional flood control facilities are constructed.
- Significant backwater conditions may occur in sheet flow areas upstream of roadways with drainage structures that are not sized for the 100-year flood. Flood depths resulting from these backwater conditions may exceed depths indicated by local geomorphology or field conditions. Required finish floor elevations should consider the potential for backwater. Finished floors should be elevated at least to 0.5 feet above the elevation of the roadway which creates the backwater conditions.

Major Development

Major developments are defined as legal subdivisions with proposed densities greater than 1 residence per acre (RAC), or industrial/commercial developments. For major developments in sheet flow areas, the following standards are recommended:

- Development should not divert or concentrate flow on adjacent properties, unless concentrated flow is conveyed in a drainage facility or natural channel with demonstrated capacity for the base flood discharge.
- Drainage studies prepared for major developments should evaluate the hydrologic impacts to the point where the sheet flow enters a drainage facility or natural channel with demonstrated capacity for the base flood discharge.
- Major facilities should be protected from scour caused by flow concentration, and from erosion of adjacent channel banks.

Methods of Flow Analysis

For development in sheet flow areas, a three-level method of analysis is proposed. Higher levels of analysis are intended to provide more accurate hydraulic data, but may require greater knowledge of hydraulics and increased expense to the floodplain manager or developer. These methodologies must be applied only in sheet flow areas, as defined above, with drainage areas greater than 0.25 square miles, or with a 100-year peak flow rates greater than 500 cfs.

Level I is the minimum level of regulation acceptable, and should be used where only limited site and flood data are available, and where site improvements are minimal. Level II requires a minimal understanding of hydraulics, and is appropriate for single lot development where some flood and site data are available. Level III analysis should be used if regional floodplain management will be impacted by the proposed development.

Level I

Minimum level of site analysis. No hydraulic analysis required. Finished floors should be elevated above the highest natural grade adjacent to the building pad as shown in Table 1, or 1.0 foot above any AO Zone on a Flood Insurance Rate Map (FIRM) for the area, unless greater flooding depths can be predicted from other readily available data, such as historical information.

Development standards outlined above in the *General Recommendations for Development in Sheet Flow Areas* section apply.

Table 1 – Level I Minimum Finished Floor Elevations (FFE)	
Drainage Area (mi²)	Minimum FFE (inches)
0.25 - 1.0	18
1.0 - 5.0	24
> 5.0	30

Level II

Estimate base flood elevation using Manning's rating³ or equivalent procedure. Note that in no case shall the minimum finished floor elevation of habitable structures be elevated less than 1.0 foot above highest adjacent natural grade adjacent to the building pad. To perform a Manning's rating the following data are needed: (1) Discharge the 100-year flow rate; (2) Topography or cross sections of site and sheet flow area; (3) Roughness Coefficient Manning's "N" value; and (4) Slope valley slope parallel to the primary flow direction. Potential data sources are described below.

Discharge

The 100-year discharge may be estimated using simplified methodologies such as ADWR State Standard #2 (SS 2-92), USGS regression equations⁴, or other appropriate local or more detailed methods. Drainage areas should be estimated conservatively to account for all possible sources of runoff. USGS topographic quadrangle maps usually provide sufficient detail for delineating watershed areas.

Topography

Topography should be obtained from the best available information. Topography should describe ground contours for both the site and the total sheet flow area. For natural sheet flow areas, topography may be obtained from USGS topographic quadrangle maps, unless better data are available. For distributary and anastomosing flow areas, topography should be obtained from detailed mapping, tape and level survey data obtained during a site visit, or estimated from aerial photography. Topographic data for distributary and anastomosing flow areas should include descriptions of channel widths, bank heights, and vegetation density. For urban sheet flow areas, descriptions of topography should include areas where flow would be blocked by buildings, fences, or other obstructions.

³ Use of Manning's equation assumes that uniform flow conditions exist. Floodplain managers should verify likelihood of uniform flow, prior to applying Level II method of analysis.

⁴ The current USGS equations are in Blakemore, 1994.

Roughness Coefficient ("N" value)

Table 2 lists roughness coefficients acceptable for use in sheet flow areas. The Manning's "N" value selected should adequately account for vegetation, sediment size, blocking of flow by flood debris, and variations in channel geometry. Several publications describe techniques for estimating "N" values (Arcement and Schneider, 1984; Thomsen and Hjaltmarson, 1991).

Table 2 Recommended Manning "N" Values for Sheet Flow Areas⁵		
Surface	N Value	Range
Concrete	.011	.010 to .013
Bare Sand	.01	.010 to .016
Gravel	.02	.012 to .03
Desert Brush	.05	.03 to .07
Natural Rangeland	.13	.01 to .32
Dense Grass	.24	.17 to .30
Bermuda Grass	.41	.30 to .48

Slope

Slope used in the rating should be the valley slope or channel slope, whichever is less. Slope may be measured from USGS topographic quadrangle maps or measured during a site visit. Slope should be measured parallel to the general direction of flow.

Minimum Elevation

In no case shall the minimum finished floor elevation of new habitable structures in sheet flow areas which meet the criteria of this standard be less than 12 inches above the highest natural existing grade adjacent to the building pad.

Level III

Full hydrologic and hydraulic analysis using computer models. Hydraulic modeling should consider the potential for a strong two- or three-dimensional character to flooding; one-dimensional computer modeling of water surfaces and depths may not be appropriate in many sheet flow areas. Two- and three-dimensional models may not be cost-effective for smaller developments. Selection and application of appropriate modeling techniques should be made

⁵ Sources: Woolhiser, D.A., 1975; Engman, E.T., 1986; Weltz, M.A., Arslan, A.B., and Lane, L.J., 1992.

by a qualified and experienced registered engineer. The FEMA alluvial fan methodology should not be used for floodplain management purposes on sheet flow areas in Arizona.

Works Cited

Arcement, G.J., Jr, and V.R. Scheider. 1984. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains: USGS Water Supply Paper 2339.

Blakemore, E.T., H.W. Hjalmarson, and S.D. Waltemeyer. "Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States." *USGS Open- File Report*. 1994. 93-419.

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Hjalmarson, H.W., and S.P. Kemna. "Flood Hazards of Distributary-Flow Areas in Southwestern Arizona." *USGS Water-Resources Investigation*. 1991. 91-4171.

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Weltz, M.A., A.B. Arslan, and L.J. Lane. "Hydraulic Roughness Coefficients for Native Rangelands." *ASCE Journal of Irrigation and Drainage Engineering*. V. 118, No. 5. 1992. Pp. 776-790.

Woolhiser, D.A. "Simulation of Unsteady Overland Flow." In K. Mahmood and V. Yevjevich, eds. *Unsteady Flow in Open Channels*. V. II. P. 502. 1975.

Test Applications

Example 1: Natural Sheet Flow

- **Problem Statement.** Single lot development proposed on 1-acre parcel with no visible channels. Area is covered by dense grass and brush. A watershed of two square miles drains toward the site, which is located in a broad, flat valley approximately 1/2-mile wide. See Figure E1.

Example 2: Distributary/Anastomosing Flow

- **Problem Statement.** Single lot development proposed on 1-acre parcel on lower portion of alluvial fan with distributary channels, and covered by desert brush with some riparian vegetation along more defined flow paths. Defined channels have sand and gravel bed material. A watershed of one square mile drains toward the site. See Figure E2.

Example 3: Urban Sheet Flow

- **Problem Statement.** Single lot development proposed on 1/6-acre parcel in residential urban area with no flood control channels or storm drains. Low flow is conveyed in the streets. Higher flows overflow into yards. Backyard areas are generally surrounded by block wall or solid fences. A watershed of one square mile drains toward the site. See Figure E3.

Example 1: Single Lot Development in Natural Sheet Flow Area

- **Description.** Dense tall grass, no defined channels, flat valley bottom
- **Discharge.** 1,000 cfs, obtained from local hydrology methodology
- **Drainage Area.** 2 square miles (mi^2 , 1280 acres)
- **Topography.** Determined by hand-level survey during site visit
- **N Value.** 0.24 (Table 2)
- **Valley Slope.** 0.009 ft/ft, measured on USGS quadrangle map for area

Results of Level I Analysis (Figure E1-b)

- **Drainage Area = 2 mi^2 .** Elevate finished floor 24 inches (2.0 ft) above highest adjacent natural grade.

Results of Level II Analysis (Figure E1-c)

- Used Manning's rating of valley section A-A' to estimate flow depth = 0.6 ft (7 inches).
- **Finished Floor Elevation = 1.6 ft.** Elevate finished floor 19 inches (1.6 ft) above highest grade adjacent to the building pad.

Results of Level III Analysis

- The advanced computer modeling of design discharge and flow hydraulics required is not illustrated here. Regardless of results of Level III analysis, the minimum finished floor elevation should be 1.0 foot above computed water surface elevation, and no less than 1.0 foot above highest adjacent grade adjacent to the building pad. Level III analysis is probably not cost-effective for this application.

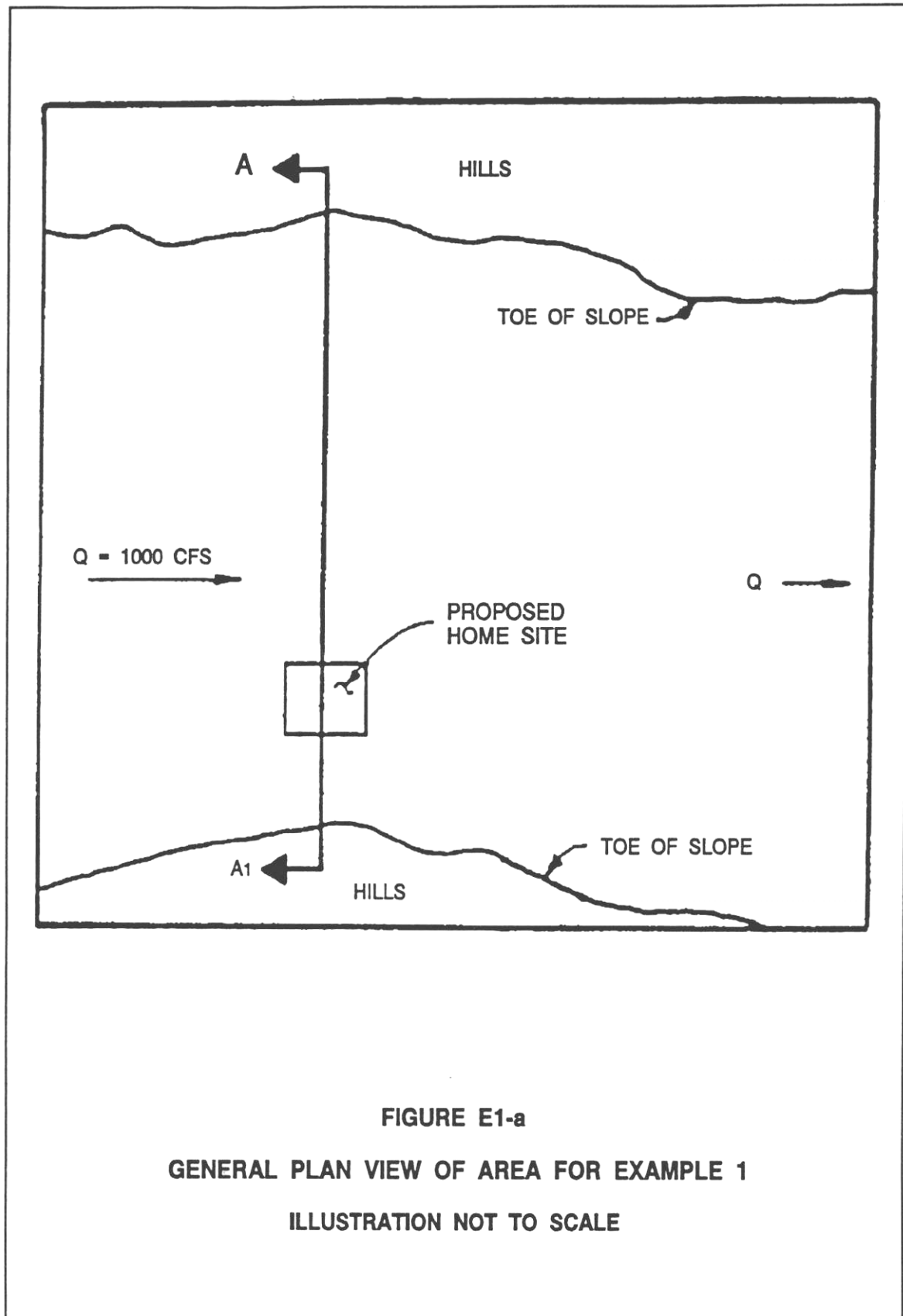


Figure E1-a

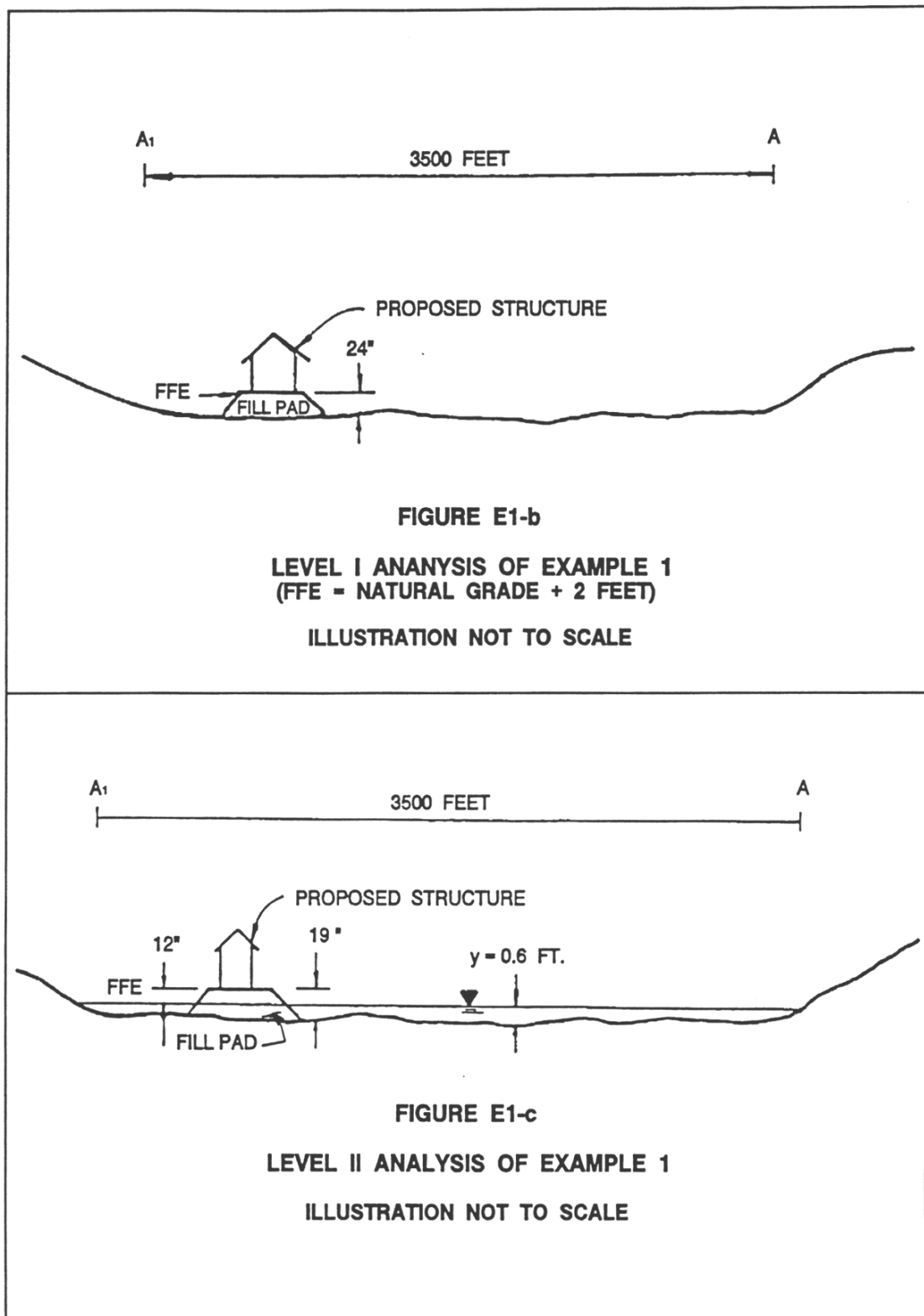


Figure E1-b and Figure E1-c

Example 2: Single Lot Development in Distributary/Anastomosing Flow Area

- **Description.** Desert brush, sand and gravel, with interconnected channels
- **Discharge.** 2,000 cfs, obtained from USGS regression equations
- **Drainage Area.** 5.2 square miles (5.2 mi², 3330 acres)
- **Topography.** Determined by tape and level survey during site visit, verified on vertical aerial (stereo) photographs
- **N Value.** 0.045 (Table 2)
- **Valley Slope.** 0.02 ft/ft, measured on USGS quadrangle

Results of Level I Analysis (Figure E2-a)

- **Drainage Area = 5.2 mi².** Elevate finished floor 30 inches (2.5 ft.) above highest adjacent natural grade (Elevation 5.9 in Figure E2-a).

Results of Level II Analysis (Figure E2-b)

- Manning's rating using HEC-2 program with single cross section, and tape and level survey points. Computed water surface elevation = 4.3 ft.
- **Finished floor elevation = 5.4 ft.** Elevate lowest floor 1.0 foot above computed water surface elevation of 4.3 ft. (5.3 ft.), and highest adjacent natural grade of 4.4 ft. (5.4 ft.). Use the higher value of 5.4 ft.
- Floodplain manager should also make judgement regarding erosion hazards.

Results Level III Analysis

- Advanced computer modeling of design discharge and flow hydraulics required. Minimum finished floor elevation 1.0 foot above computed water surface elevation, and no less than 1.0 foot above highest adjacent grade adjacent to the building pad.

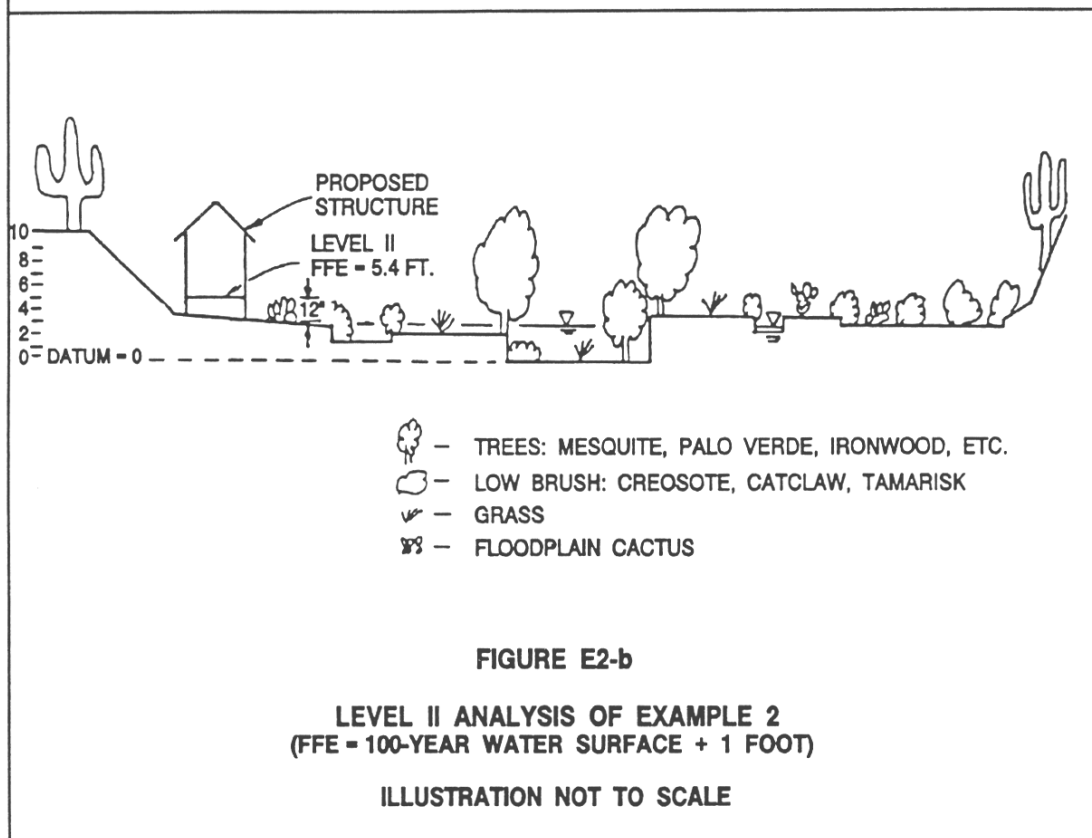
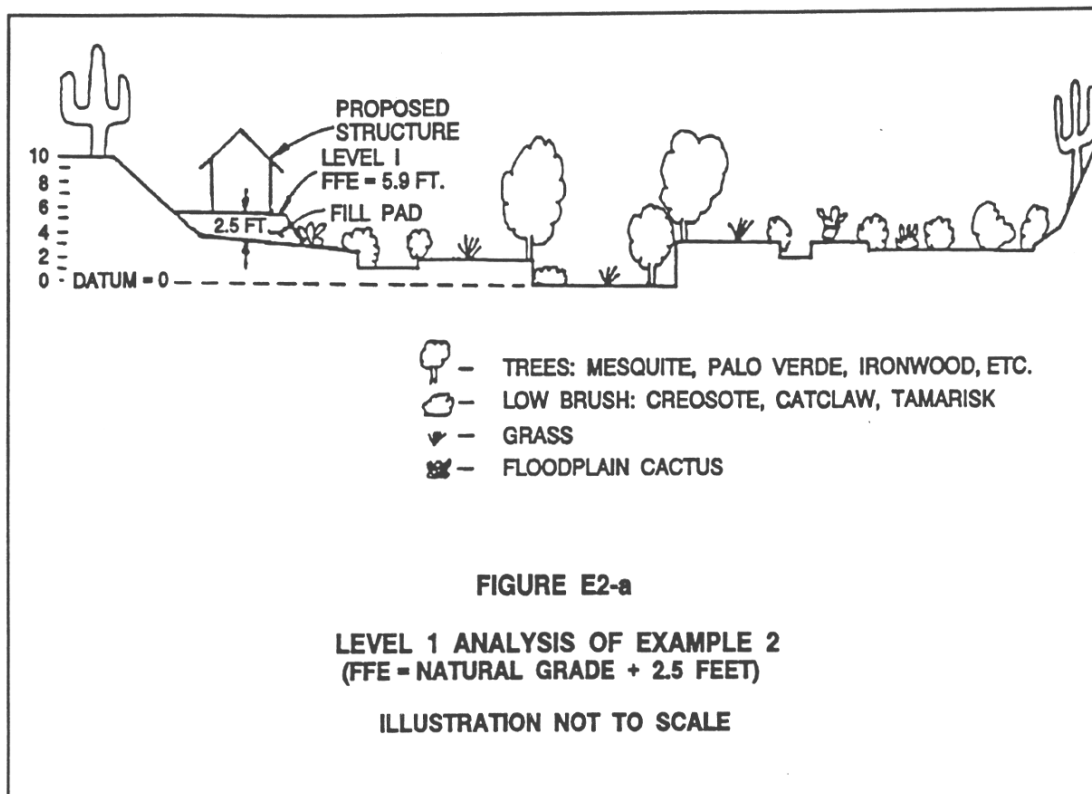


Figure E2-a and Figure E2-b

Example 3: Urban Sheet Flow

- **Description.** Residential landscaping, with perimeter walls between lots
- **Discharge.** 2,000 cfs, obtained from State Standard 92-02.
- **Drainage Area.** 1.5 square miles (1.5 mi², 960 acres)
- **Topography.** Determined from 1:1200, 2 ft contour interval mapping by local community, checked during site visit
- **N Value.** 0.3 for landscaping, 0.011 for streets and sidewalks, block out fence and home areas (Table 2)
- **Valley Slope.** 0.005 ft/ft, measured on detailed city topography

Results of Level I Analysis (Figure E3-a)

- **Drainage Area 1.5 mi².** Elevate finished floor 24 inches (2.0 ft) above natural grade. (Elevation 4.5 in Figure E3-a.)

Results of Level II Analysis (Figure E3-b)

- Manning's rating using HEC-2 program with single cross section, and ground elevation points from topographic map. Computed water surface elevation = 3.0 ft.
- Finished floor elevation = 4.0 ft, but no less than 1.0 foot above highest grade adjacent to the building pad (grade at 2.5 ft in Figure E2-b).

Results of Level III Analysis

- Advanced computer modeling of design discharge and flow hydraulics required. Minimum finished floor elevation 1.0 foot above computed water surface elevation, and no less than 1.0 foot above highest adjacent grade adjacent to the building pad.

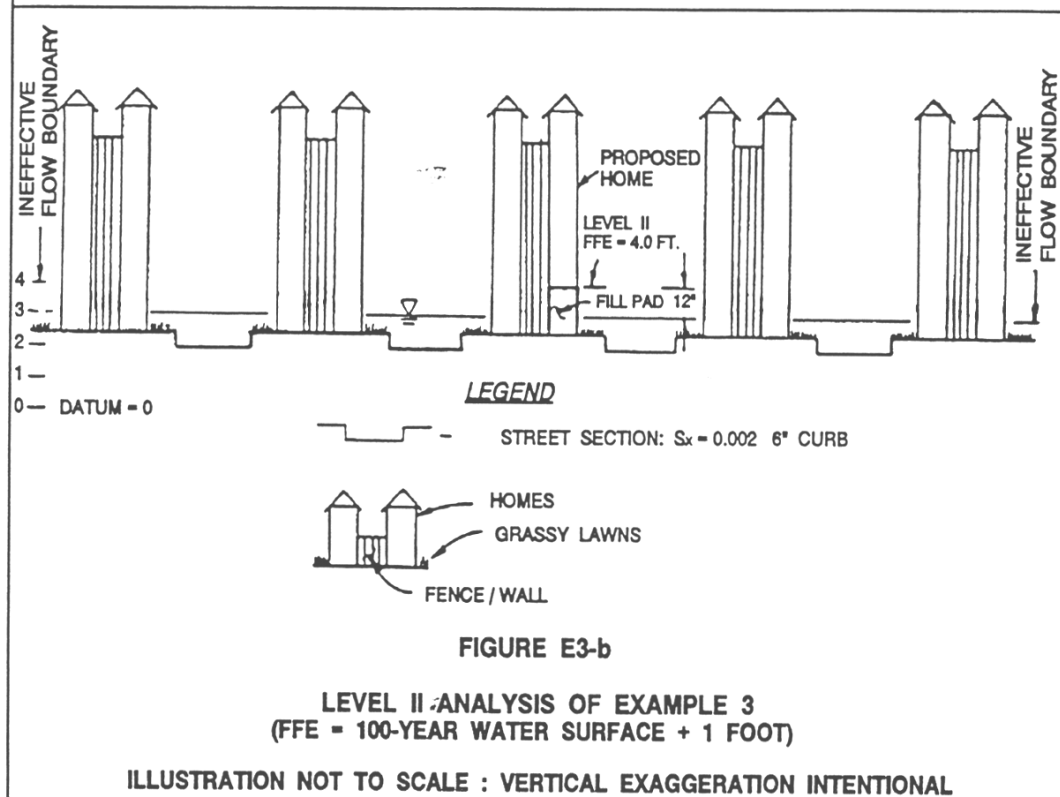
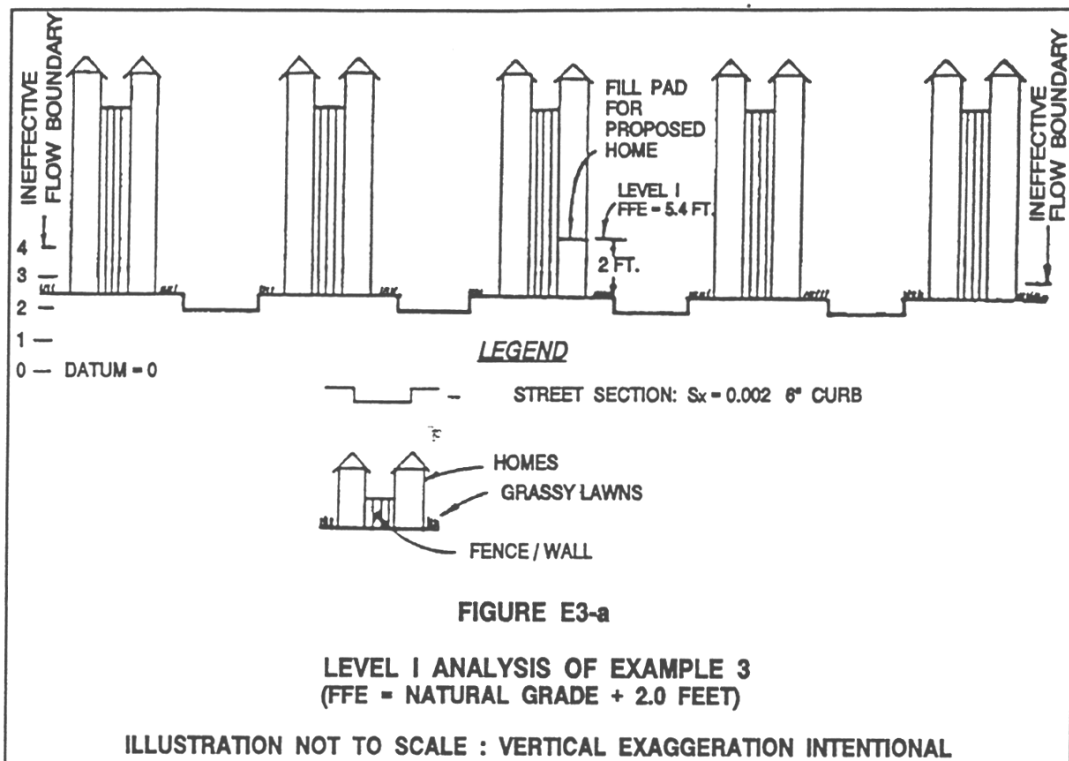


Figure E3-a and Figure E3-b